

Tutorial

Stimulus Control: Part II

James A. Dinsmoor
Indiana University

The second part of my tutorial stresses the systematic importance of two parameters of discrimination training: (a) the magnitude of the physical difference between the positive and the negative stimulus (disparity) and (b) the magnitude of the difference between the positive stimulus, in particular, and the background stimulation (salience). It then examines the role these variables play in such complex phenomena as blocking and overshadowing, progressive discrimination training, and the transfer of control by fading. It concludes by considering concept formation and imitation, which are important forms of application, and recent work on equivalence relations.

Key words: stimulus control, disparity, salience, blocking, overshadowing, transfer, fading, concept formation, imitation, equivalence relations

The first part of this tutorial dealt with the basic principles that account for the acquisition of stimulus control under what is conventionally known as discrimination training. Among the salient points that were raised were suggestions that (a) control by antecedent stimuli is just as important in operant as it is in respondent behavior; (b) Pavlov's conditional stimulus is a discriminative stimulus; (c) stimulus generalization is not a behavioral process independent of and antagonistic to discrimination but is simply another way of describing control by antecedent stimuli; and (d) the increases in control that occur during discrimination training can be attributed to more frequent and more prolonged observation of the relevant stimuli accompanied, it is presumed, by concomitant changes in attention.

Note that in conventional discrimination training, the subject is exposed to repeated alternations between the positive stimulus (S+), which is accompanied by a schedule of reinforcement, and an alternative stimulus (S-), which is not accompanied by reinforcement. This alternation establishes

a positive correlation between the S+ and the primary reinforcer that selects the one relevant stimulus out of the many that impinge upon the organism and transforms it into a conditioned reinforcer of observing behavior. Note also that if the subject is exposed exclusively to S+ training or to a single period of S+ training followed by a single period of S- training rather than to a continued alternation, control is less adequate (Honig, Thomas, & Guttman, 1959; Yarczower & Switalski, 1969). Similarly, in a compound discrimination like that studied by Blough (1969), if one dimension is left continuously at its positive value for a number of sessions, control by that dimension is reduced and control by the other dimension enhanced; when the procedure returns to the previous alternation between positive and negative stimuli, the discriminative performance returns to its normal level.

The second part of my tutorial will necessarily be less tightly integrated. Taking off from the foundation laid in Part I, it extends the treatment of stimulus control to a discussion of two of its most important parameters and to several more complex patterns that seem to hold special significance for basic theorizing and practical application.

Address correspondence to James A. Dinsmoor, Department of Psychology, Indiana University, Bloomington, Indiana 47405.

STIMULUS PARAMETERS

There are a number of variables that influence the rate at which the subject learns to discriminate between stimuli and the level of performance that will ultimately be attained. However, some of these, like the physical quality of the stimulus (e.g., wavelength of light, energy of sound), the topography of the response, and individual and species differences among different subjects, do not readily lend themselves to the formulation of general laws of behavior. Of greater interest from a systematic point of view are those parameters that enter into a variety of behavioral paradigms. There are two parameters, in particular, that will appear and reappear in subsequent accounts of topics like overshadowing, blocking, the easy-to-hard effect, fading, and concept formation. These are (a) the magnitude of the difference in physical units between the positive and the negative stimulus, sometimes subsumed by the phrase *stimulus disparity*, and (b) the magnitude of the difference between the discriminative stimuli and the background stimulation, subsumed as *stimulus salience*.

Stimulus Disparity

Clearcut evidence for the role played by the disparity between the two stimuli may be found in a series of early studies, using rats as subjects, conducted by Rosemary Pierrel and her associates at Brown University. Bar pressing was reinforced on a variable-interval schedule in the presence of the positive stimulus but not in the presence of the negative stimulus. In Pierrel, Sherman, Blue, and Hegge (1970), for example, the discriminative stimuli were pulsed tones of 4 kHz that differed in intensity. The difference between the positive and the negative stimulus was set at 10, 20, 30, or 40 dB, with the higher intensity serving as the positive stimulus for half the groups and as the negative stimulus for the other half. Also, for half the animals, independently assigned, the low-

er intensity was set at 60 dB, with the higher intensity determined by the magnitude of the difference between the two; for the other half, the higher intensity was set at 100 dB, with the lower intensity determined by the magnitude of the difference. (Because there was only one 60-100 group and one 100-60 group, there were 14 rather than 16 groups in all, plus a special control group.)

It seems obvious that very small physical differences between the positive stimulus (S^+ or S^+) and the negative stimulus (S^- or S^-) must be difficult to discriminate. Up to some limit, at least, larger differences should promote faster acquisition and a larger ultimate difference between the two performances. This expectation is borne out by a series of plots tracing the course of the discrimination index (multiplied by 10) as a function of the hours of training. In all four panels of Figure 1, the discrimination is slowest to develop and attains the lowest final level in groups for which the stimuli differ by only 10 dB; groups for which the difference is 20 dB do somewhat better; groups for which the difference is 30 or 40 dB differ less during acquisition and tend to converge, but at still higher levels of performance. With pigeons as subjects, Hanson (1959) found a similar relation between the magnitude of the difference in wavelength and the time required for the development of a discrimination. Again the slope of the function was steep at small values but decreased as larger values were approached.

Stimulus Salience

Further examples of the effects of stimulus disparity would not be hard to find, but the magnitude of the difference between the discriminative stimuli and their background stimulation (salience) poses more of a problem. This is a dimension that does not come up for consideration within the older response-strengthening-and-weakening theories of discrimination learning.

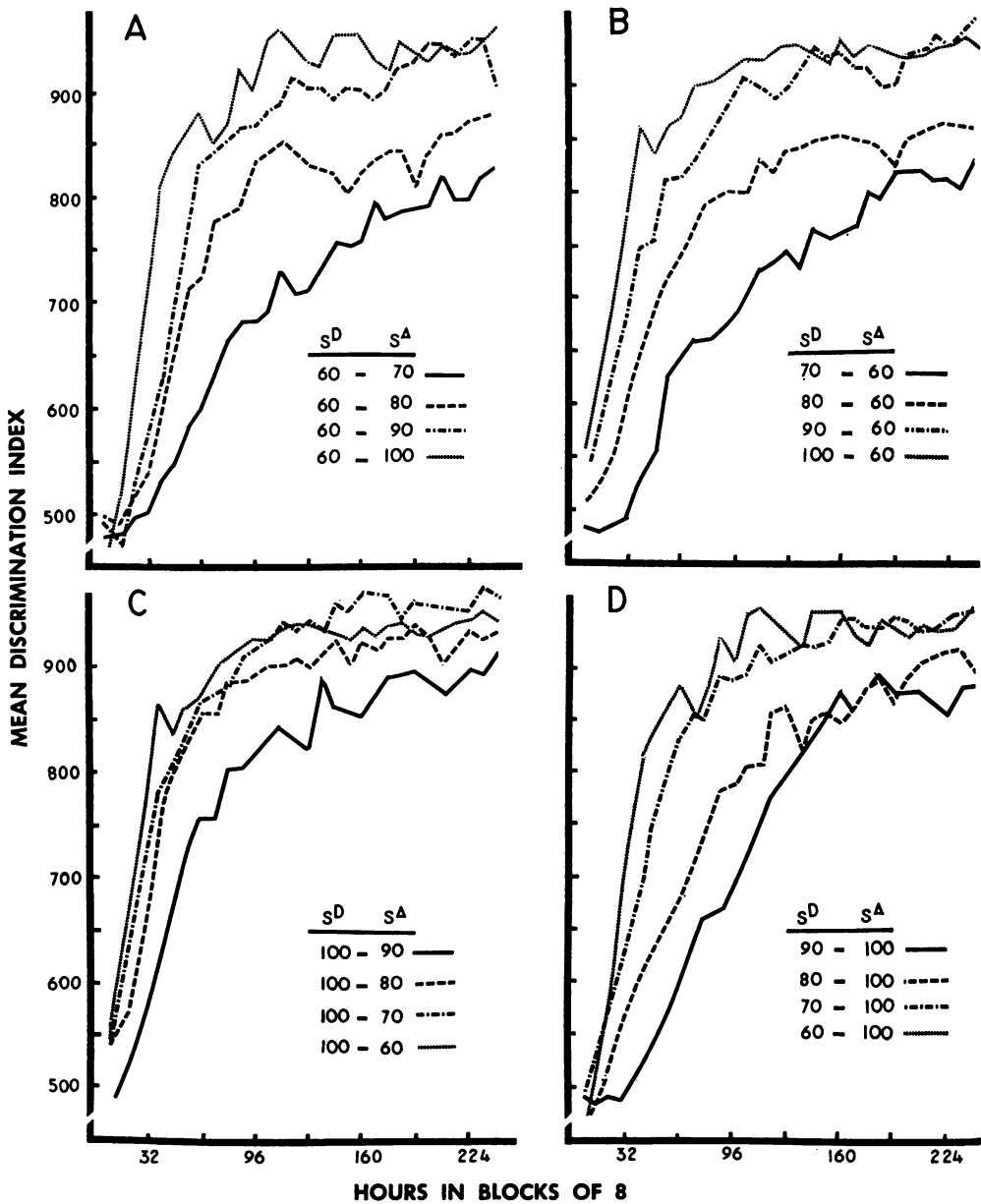


Figure 1. Percentage of responding in S^P (S⁺), multiplied by 10, as a function of hours of training. Each point represents the mean of 4 rats during an 8-hr session. The stimuli for each group are specified in decibels. (Reproduced from Pierrel et al., 1970; copyright Society for the Experimental Analysis of Behavior.)

However, when investigators are guided by an interest in the role of observing or attention, it becomes a more likely candidate. In my laboratory, we became aware of the importance of salience while studying the effects of

stimulus disparity on the relative rates of pecking two observing keys (Dinsmoor, Sears, & Dout, 1976). In our first experiment, the birds pecked a key that produced large increases or decreases in illumination as discriminative stim-

uli at higher rates than they pecked a key that produced smaller increases or decreases in illumination. In our second experiment, however, we varied the magnitude of change for the positive and the negative stimuli independently. We discovered that the positive relation between magnitude of change and rate of pecking stemmed entirely from the positive stimulus: For the negative stimulus, the function was negative in slope. That is, larger changes in stimulation reduced the rate. On returning to the experimental literature, we were led to the conclusion that in most previous examinations of stimulus difference, the magnitude of the difference between the two stimuli had been confounded with the magnitude of the difference between the discriminative stimuli and their background. That is, the disparity between the stimuli had been confounded with their salience.

At the time, we were not aware that a study of discrimination in which the salience of the stimuli had indeed been varied independently of other factors had already been conducted by Johnson (1970). A student of Cumming, Johnson was interested in the role of attention in discrimination learning, and one of the parameters he had varied, as part of a larger study of selective control, was the brightness of a white line displayed on the pigeon's key. Pecks when the line was vertical (S+) were reinforced on a random-interval schedule, but pecks when the line was horizontal (S-) were never reinforced. The rate at which the birds learned the discrimination between these two orientations was a function of the brightness of the line.

Still blithely unaware of Johnson's study, Dinsmoor, Mueller, Martin, and Bowe (1982) chose as their controlling stimulus a black line bisecting a white key. Pecks on the key produced grain on a variable-interval schedule that alternated with an extinction schedule. Ordinarily, the line remained horizontal in its alignment, regardless of which of these schedules was operating. But

by depressing a low-lying "perch," similar to the conventional cross-bar for rats, the pigeon produced stimuli that were correlated with the component schedules. During periods when the variable-interval schedule was in effect, the stimulus was, for two different groups, a clockwise tilt of 15° or a clockwise tilt of 30° (S+); during periods when the grain was being withheld, it was a counterclockwise tilt of the same magnitude (S-). For half of the subjects, then, the total difference between the two tilts was 30°, and for the other half, it was 60°. These differences represented small and large disparities, respectively, between the two stimuli.

To vary the salience of the stimuli, the experimenters used an arrangement similar to that of Johnson (1970), reducing the contrast between the black line, regardless of its tilt, and the white surround. This was accomplished by the simultaneous lighting of two projection units, one of which displayed an image of the line on the key and the other of which produced only a uniform white field. Both lamps were reduced to 50% of their normal intensity. Thus, the salience of the stimuli could be manipulated without affecting their disparity. When the image of the line was projected at its maximal contrast by a single projector cell, 7 of the 8 birds in that group learned both to hold down the perch and to discriminate in their rate of pecking between the resulting stimuli. When the second cell was lighted, the line, now gray, was readily visible to the human eye and presumably to that of the pigeon. Nevertheless, only 1 of the 8 birds in the other group gave any indication that its behavior was influenced by the tilt of the line. Obviously, the salience of the stimuli was an important determinant of the level of observing and of the consequent level of discrimination. The effects of disparity were not as clear as those for salience, but in a subsequent study, using an entirely different design, Dinsmoor et al. (1983) found that both of these dimensions af-

affected the rate at which pigeons pecked an observing key.

SELECTIVE CONTROL

It was Pavlov (1927/1960, pp. 141ff.) who first called attention to the reduction in the effectiveness of a stimulus that sometimes occurred when that stimulus was presented in tandem with another stimulus. He found that when two conditional stimuli were regularly presented together, in the same temporal relation to each presentation of the unconditional stimulus, one member of the pair often came to assume complete control over the amount of saliva that was secreted, to the partial or complete exclusion of the other stimulus. That is, when tested alone, the second stimulus was ineffective. On further examination, he found that it was the relative intensity of the two conditional stimuli (CSs) that determined which of them prevailed and the extent to which the effectiveness of the less intense stimulus was reduced. When the stimuli were of equal intensity (e.g., two tones of equal loudness), the phenomenon did not appear: The two stimuli were followed by responses of equal magnitude. Pavlov therefore spoke of the more intense CS as "obscuring" or "overshadowing" the less intense CS.

Years later, at the Miami Symposium on the Prediction of Behavior, Kamin (1968) presented a series of experimental comparisons that provided convincing evidence not only for overshadowing but also for another phenomenon, also based on the simultaneous presentation of two stimuli. In this case, the dominance of one stimulus over the other was not established by its intensity but by prior training. If the subject was trained first with a single CS and later with a compound that included the original and some other stimulus, the added CS turned out to be ineffective. Kamin spoke of the prior training with the first stimulus as "blocking" the subsequent acquisition of control by the second stimulus. In

the same year, a set of experiments published by Wagner, Logan, Haberlandt, and Price (1968) implicated yet a third variable, the consistency with which each member of the stimulus compound was followed by the unconditional stimulus (US). A CS that was always followed by the US reduced the effectiveness of a stimulus that was followed by the US on only half of its presentations.

The common thread running through the loss of effectiveness in each of these instances is that both stimuli are regularly presented at the same time and therefore in the same temporal locus with regard to the unconditional stimulus. Other ways of describing the relation between the two CSs are to say that they covary, that they are confounded, or that they duplicate one another. Cognitive psychologists often refer to the second stimulus as "redundant," meaning that it provides no additional information concerning the arrival of the US (i.e., no improvement in the prediction of the US over that provided by the first stimulus). Both stimuli convey the same meaning. In courses on composition, the word *redundant* is sometimes used to refer to the type of error manifested by a speaker who proclaims that "We've won four straight in a row." *In a row* conveys the same information as *straight*, and the repetition is jarring. (Sometimes, however, a more remote and less conspicuous redundancy is effective in expository writing.)

Blocking and overshadowing have also been observed with operant behavior. The primary difference in procedure is that instead of the stimulus control being based exclusively on the presence versus the absence of a CS, as in respondent conditioning, in operant work the discrimination is recognized, and both a positive stimulus and an explicit negative stimulus are normally provided. In a study by vom Saal and Jenkins (1970), for example, pecking was initially reinforced in the presence of green illumination of the key but not in the presence of red; later

a tone and a noise were added to the procedure, covarying with the first pair of stimuli; and finally, control by the tone and noise alone was compared with control by those same stimuli in a group of birds that had not been pre-trained with the red and the green. The prior training on the red-green discrimination was found to have blocked the acquisition of control by the tone and the noise.

In a study of overshadowing, Miles and Jenkins (1973) reinforced pecking in the presence of a bright light and a tone of 1000 Hz (S+) but not in the presence of a light of lower intensity and a white noise (S-). The intensity of the second light varied from group to group. In subsequent tests, the tone had relatively little influence over the responding by birds in the group that had received the largest difference in illumination (brightest light vs. total darkness) but exerted much more control with birds that had been trained with smaller differences in illumination. The easier the light discrimination, the more it overshadowed the tone. The harder the light discrimination, the less it overshadowed the tone.

Note that in this experiment the variable that determined the amount of overshadowing was not the absolute intensity of the S+ (which remained the same from group to group) but the size of the difference between that S+ and the corresponding S- (stimulus disparity). This may have been the critical variable in the respondent work as well, because the absolute intensity of the CS (which was assumed to be the relevant dimension) was always confounded with the magnitude of its difference from the absence of the CS (disparity). Recognizing that the conditional stimulus is a discriminative stimulus enables us to formulate broader, more general principles of behavior.

Blocking and overshadowing have figured prominently in theoretical discussions about Pavlovian conditioning, but at a more applied level they have largely been ignored. I suspect that their manifestations appear fairly fre-

quently in everyday life and that over a period of time a good many illustrations may be found. For the present, one example that comes to mind is a phenomenon, well known to social psychologists, in which individual members of an outgroup who share a prominent physical characteristic are perceived as "all looking alike." (For a recent list of citations, see Anthony, Copper, & Mullen, 1992.) That is, for each individual, the characteristic common to all members of the group overshadows the characteristics distinctive of that one individual and makes different members of the group more difficult to discriminate.

Two major types of explanation have been offered for blocking and overshadowing. Rescorla and Wagner (1972) have proposed an elegantly simple mathematical model of Pavlovian conditioning, suggested directly by Kamin's (1968) data, that accounts for these phenomena in terms of a ceiling on the level of associative strength. When one stimulus is relatively intense or is presented earlier in training, the overall strength of conditioning based on that stimulus approaches an asymptote, and little additional conditioning can occur to a second stimulus that is less intense or is introduced later in training. Theoretical descriptions of this type (see also Revusky, 1971), however, do not account for instances in which overshadowing has been demonstrated on the first trial of conditioning (e.g., Mackintosh & Reese, 1979).

The other type of explanation that has been popular in discussions of blocking and overshadowing relates the reduction in effectiveness to a failure to observe or to attend to the second stimulus or pair of stimuli (e.g., Mackintosh, 1974, pp. 585ff.). Some support for this interpretation may be found in experiments on observing behavior. Two replications of such an experiment were conducted in my laboratory. In the first one, some of the data were disrupted when we were required to remove the birds from their usual

living quarters. Then the second one became to a certain extent redundant scientifically when a similar study was published by Blanchard (1977). In our experiments, which were somewhat more complex than Blanchard's, we provided the pigeon with an observing key that altered the tilt of a white line displayed on a colored ground. During periods when food was being programmed on a variable-interval schedule, pecking the observing key intermittently produced a shift in the orientation of the line, rotating it 45° from the horizontal; during periods when no food was scheduled (extinction), the shift was in the opposite direction. Meanwhile, the colored backgrounds switched back and forth on a schedule that was unrelated to the schedules of food delivery and the direction of the rotation produced by pecking the observing key. On some sessions the alternating colors differed by a large amount, and on other sessions they differed by a small amount.

After the rate of pecking had stabilized, however, we synchronized the alternations of the colors with the alternations between the variable-interval schedule and extinction and with the direction taken by the line. At this point, the changes in the orientation of the line produced by pecking the observing key became completely redundant: Whenever such a change was produced, its relation to the delivery of food was exactly the same as that of a color already displayed on the key. As would be expected, the rate of pecking the observing key in the presence of one of the S- colors (pecking that produced only S- tilts) dropped precipitously. Much more important was the fact that the rate of pecking in the presence of one of the S+ colors also declined. In other words, less observing behavior was maintained by the line tilts as conditioned reinforcers when they covaried with another, more effective set of stimuli. Moreover, in accord with conventional experiments on overshadowing, when the colors that differed by a large amount were dis-

played on the key, the rate of pecking dropped more than when the colors that differed by a small amount were displayed.

At a broad and general level, then, a model based on principles derived from the study of observing can account for the effects of continued training, as well as for the overshadowing sometimes noted on the initial trial. On the other hand, it is difficult to see how any model based on the observation of or attention to one stimulus rather than another could handle the results obtained by Revusky (1971), which mimic blocking and overshadowing despite the absence of any temporal overlap between the two conditional stimuli. Perhaps no single factor can account for all of the data obtained in experiments on blocking and overshadowing.

Progressive Discrimination

Another phenomenon that highlights the importance of the magnitude of the difference between the stimuli to be discriminated (disparity) is known variously as progressive discrimination training, transfer along a continuum, or the easy-to-hard effect. It has long been recognized that the most efficient way to train a subject to discriminate between two stimuli that lie close together along the physical continuum is to begin with stimuli that are farther apart and then, in successive steps, to close the gap (e.g., James, 1890, p. 515; Montessori, 1912, p. 184). In other words, initial training with easy stimuli from the same dimension accomplishes more than an equal period of training with the difficult pair on which the subject is eventually to be tested. In Pavlov's laboratory, this technique was employed to train a dog to discriminate between a light gray and a white circle and to train another to discriminate between a fairly well-rounded ellipse and a perfect circle (Pavlov, 1927/1960, pp. 121ff.).

Even before bar-pressing or key-pecking techniques came into common use, systematic data were reported with

relatively crude procedures, typically involving choices between test cards of differing shades of gray. The study that has been most widely cited, historically, is one reported by Lawrence (1952). In his procedure, the rat was forced to jump across a gap that separated the starting box from a pair of goal compartments lined with cardboard in differing shades of gray. One group of subjects was trained throughout with two highly similar grays, the same as those used in the final test; two groups started with the lightest and the darkest gray and were shifted to the final test pair at different points in their training; and finally, one group received its first 10 trials with the most disparate pair of grays, the next 10 trials with a less disparate pair, the third 10 trials with a still less disparate pair, and its last 50 trials with the final test pair. All the groups that began with the large difference performed better during their last 50 trials than did the group that began with the difficult discrimination. The last group, which shifted in a series of steps, made the fewest errors of all the groups. Lawrence suggested that the easy stimuli facilitated later learning of the hard stimuli because they helped "the animal to isolate functionally the relevant stimulus dimension from all the other background and irrelevant cues" (Lawrence, 1952, p. 516). Both the magnitude of the disparity between the positive and the negative stimulus and the salience of the positive stimulus, which is confounded with its disparity in many of these studies, contribute to the effective reinforcement of relevant observing behavior (Dinsmoor et al., 1983).

Fading

In contrast to the research on blocking and overshadowing, which was concerned exclusively with an elucidation of the basic principles of conditioning, the original impetus to research on fading seems to have emanated from attempts to fashion effective techniques for use in programmed

instruction. Early papers (Cook, 1960; Skinner, 1958) describe a procedure then known as "vanishing": In successive steps, letters were eliminated from words to be spelled by the subject, words were deleted from passages to be recited from memory, or labels for various geographical features were removed from a map. The subject continued to respond correctly, despite the elimination of the original stimuli, even when the only remaining cues might be those generated by chains of ongoing behavior.

Almost immediately, there was a change in terminology, and the same technique came to be known as "fading" (Holland, 1960). Then, not long after that, investigators using nonhuman subjects began studying fading in the conditioning laboratory. Using a highly specialized training procedure, Terrace (1963) had initially established a discrimination between red and green illumination of the pigeon's key. Although he did not point out the parallel, the red and the green were equivalent to the stimuli that were already effective when a human trainee began his or her program of instruction. Then a vertical line was superimposed on the red S+ and a horizontal line on the green S-. Gradually, in successive steps, the brightness of the red and the green was reduced, until the key became totally dark except for the lines. In other words, the red and the green illumination were faded. As the salience of the colors was reduced, the birds made less and less use of those stimuli and gradually came to depend on the direction taken by the line. In two replications of this transfer procedure, a total of 4 birds learned the vertical-horizontal discrimination without ever pecking in the presence of the S- (i.e., without making a single error).

Other techniques, used as experimental controls, proved to be far less effective. For example, if the red and the green were completely removed from the key at the time that the vertical and the horizontal lines were introduced, so that there was no temporal

overlap between the two sets of stimuli, hundreds of S- responses occurred before the birds learned the vertical-horizontal discrimination. When the two sets of stimuli overlapped in time but nothing was done during this time to reduce the effectiveness of the red and the green, intermediate results were obtained. Something was evidently learned with regard to the lines during the period when they were superimposed on the colors, but not as much. It was the gradual reduction in the salience of the colors that forced the birds in the fading group to switch to the lines during the period when both sets of stimuli were available. By the time the colors were completely gone, the birds had already learned to discriminate accurately on the basis of the lines. (For an alternative procedure in which the original stimuli were delayed in onset rather than reduced in salience, see Touchette, 1971.)

There is another parallel that was not obvious at the time Terrace conducted his work: His red and green illumination were also comparable to the pre-trained or inherently more effective stimuli subsequently used in operant studies of blocking and overshadowing. In light of this correspondence, Terrace's (1963) fading procedure can be viewed as a method of overcoming the overshadowing or undoing the blocking of one pair of stimuli by another. By reducing the influence of the originally dominant pair, fading allows the stimuli that have been blocked or overshadowed to gain effectiveness.

The advantage offered by Terrace's (1963) fading procedure was that during the prior training, highly effective stimuli were available on the key. In contrast to the lines, which were more localized, the colors covered the entire surface of the key, and anywhere the pigeon might initially look while pecking that key it was likely to see the color. Early contact with a stimulus correlated with reinforcement produced early acquisition and a high level of performance of the behavior by which the bird observed that stimulus.

Later, when the lines were introduced, the birds had already learned to look at and attend to stimuli displayed on the key. The lines were displayed in the same general location as the colors (i.e., on the surface of the key). Then, as the salience of the colors was reduced, their value as reinforcers declined (Dinsmoor et al., 1982, 1983) and the bird shifted from observing the colors to observing the lines.

Evidence confirming this interpretation comes from a study conducted by Fields (1978). Again the pigeons were pre-trained to discriminate between red and green illumination of the key. Then white lines of differing orientation were superimposed on the red and green backgrounds. Between blocks of training trials, Fields inserted probe trials on which he presented the same white lines, but on a dark background. These trials enabled him to track the acquisition of the line discrimination during the course of training.

The most revealing aspect of Fields' (1978) procedure was that with one group of subjects he faded both the red and the green, with another group he faded only the red (S+), leaving the green at its original intensity, and with a third group he faded only the green (S-), leaving the red at its original intensity. Interpretation of the difference in results between the first two of these groups is complex and need not concern us here, but the interesting finding occurred with the third group. Data from a large number of experiments indicate that it is the S+ that reinforces observing (for a review of these data, see Dinsmoor, 1983). Accordingly, an interpretation in terms of the observing paradigm predicts, uniquely I think, that it is fading of the S+ that is required to transfer control of pecking from the colors to the direction taken by the lines. Fading of the S- should have no effect. And that is the result that Fields obtained. "Attenuation of the S- alone . . . did not produce stimulus control by the line-tilt dimension" (Fields, 1978, p. 126). His Figure 1 showed no pecking to either S+ or S-

probes when it was the green (S-) illumination that was faded.

CONCEPT FORMATION

When, in everyday conversation, people speak of someone "possessing" a certain concept, it is taken for granted that they are referring to some kind of unobservable content or state of the mind. But when we examine the matter, we find that the observation that leads them to use the term *concept* is that the person responds in the same way to a set of objects or relations that have some characteristic or set of characteristics in common but does not respond in that same way to other objects or relations. All birds are called birds, for example, but no snakes, squirrels, or sheep. As Keller and Schoenfeld put it, "Generalization within classes and discrimination between classes" (1950, p. 155).

If we can verbalize what it is that the various instances have in common, we may be able to define the concept, but often this can be very difficult. Try defining what is meant even by such familiar categories as a "dog," for example, or a "human being." Are you sure you did not include wolves or coyotes in the first instance or chimpanzees in the second? Did you include feral children? Definition is secondary to the behavior: In essence, it is a description of that behavior, although it can provide in turn a rule for increasing the accuracy of that behavior or for passing it along to another person (e.g., Skinner, 1969, pp. 121-125, 136-142).

Laboratory research on the formation of concepts arose from an interest in the processes of human thought and has continued for many years in almost complete isolation from research on the formation of discriminations. The general nature of the procedure is illustrated by an experiment conducted by Trabasso (1963). College students were presented with drawings of flowers, in a randomized sequence, and were asked to classify each drawing by

calling it an A or a B. Four different varieties of flower were used, and each of these varied also in the shape of its leaves, the angle of the leaves to the stem, and the number of leaves on either side. For most of the subjects, the angle with the stem was the relevant feature (i.e., the discriminative stimulus), determining whether A or B was the response to be reinforced. Trabasso found that such strategies as holding other features constant, rather than allowing them to vary, and, as in ordinary discrimination training, increasing the difference between the positive and the negative angles (i.e., disparity), or increasing their difference from the background stimulation by coloring them red (i.e., salience) all led to faster acquisition of the correct categorization. These findings suggest that concept formation is very similar to discrimination training. In particular, the effect of highlighting the angles to increase their salience indicates that a major part of the subject's task is to learn to observe the appropriate feature within the field of stimulation.

Traditionally, as I have indicated, psychologists have treated experiments dealing with the formation of discriminations and experiments dealing with the formation of concepts as two separate and distinct fields of inquiry. But the close relation between the two has long been recognized by some writers (e.g., Keller & Schoenfeld, 1950), and whether the traditional distinction is justified is open to question.

It is true that most of the work on discrimination learning has been carried out with rats, pigeons, and monkeys, whereas most of the experiments on concept formation have been conducted with human subjects. This reflects the differences in the historical origins and rationales of the two types of research. But there is no hard and fast rule: Sometimes humans are used to study discrimination learning, and sometimes other species are used to study the acquisition of concepts.

Another common difference between the two types of experiment is

probably a result of the first. Because an entire set of verbal responses can readily and quickly be established with members of the human species, human subjects may be asked to acquire several different concepts at the same time. This practice enables the experimenter to collect more data from each subject. When other species are used, however, it takes much longer to establish each response topography, and the use of any substantial number of categories becomes impractical, even in those experiments designated as studies of concept formation. To respond or not to respond is usually the question.

A third feature, which may also relate to the historic use of human subjects, is that in experiments on concept formation the distinction between the positive and the negative stimulus is often very subtle. Human subjects learn simple, gross discriminations so rapidly that variations in their performance created by manipulating some independent variable might be too small to detect, and subtle differences are necessary to collect meaningful data. In this case, the historical feature may have been extended to serve as an implicit definition for classifying the two types of research: Even when non-human species are used, subtlety of the properties distinguishing between the positive and the negative instances (e.g., Herrnstein, Loveland, & Cable, 1976) appears to be characteristic of those experiments that are considered to be examples of concept formation. But this is a difference in a parametric value, not a difference in the underlying process.

Finally, the most meaningful difference between discrimination and concept formation may be that in experiments on discrimination, all aspects of the environment other than the alternation between the positive and the negative stimulus are kept as uniform as possible ("held constant"), so that they will produce the least possible fluctuation in the results. In experiments on concept formation, by contrast, other aspects of the stimulus ob-

ject are deliberately varied. In this respect, experiments on concept formation are more closely related to what is colloquially called "real life." They provide us with a persuasive bridge between the stripped down simplicity of the laboratory and the rich complexity of the natural setting.

IMITATION

There is another form of stimulus control that is not well understood but that merits consideration because it is believed to play an enormous role in training the young of many species, including our own, to behave like their parents and other adults. The observation that leads us to speak of imitation is that the stimulus setting the occasion for a particular response or set of responses is the performance of approximately the same pattern of behavior by another individual, usually of the same species. Such a correspondence between two patterns of behavior is so common that it is frequently assumed that it must be the result of some intrinsic connection between the behavior of the second organism and that of the first. But not all behavior is imitated. In most cases in which imitation is said to occur, the correspondence between the two sets of behavior appears to be historical in origin. It is a product of the contingencies of reinforcement.

It has sometimes been suggested (e.g., Bandura, 1965) that imitation is an alternative mode of learning, by means of which a response can be established without the use of reinforcement ("no-trial learning"). In some sense, at a global level, this may be true, but it is not clear that any new principle of behavior is required to explain Bandura's results.

In exploring this issue, it may be helpful to distinguish between a complex pattern of physical activity like swimming the breast stroke, riding a bicycle, driving an automobile, or performing a new dance step, and the constituent movements that make it up (see Guthrie, 1952, pp. 27-28, or Skin-

ner, 1953, p. 94). Modeling is akin to verbal instruction, and, indeed, might be considered another form of the same process. If the constituent responses are already a part of the individual's repertoire (by prior differentiation) and some kind of imitative control has already been established, an appropriate sequence or an effective combination of responses can often be called forth by the corresponding behavior of a model. Sometimes this is all that is needed. In other cases, it may still serve as the initial step: Once some approximation to the appropriate behavior has occurred, the overall pattern can be maintained and can subsequently be refined by selective reinforcement. But if the constituent responses are not in the individual's repertoire to begin with, they cannot be established simply by imitation. Who among us has not struggled in vain to match the sounds that have been demonstrated to us by the teacher of a foreign language, only to find that the closest approximations within our vocal repertoire leave much to be desired? Who among us has not tried to copy someone else's drawing, only to discover that much more training was necessary before a satisfactory replica could be produced?

The process by which the correspondence between stimulus and response is originally established was illustrated more than half a century ago in an experiment by Miller and Dollard (1940). All training was conducted on a special maze, shaped like the letter T. First, several "leader" rats were trained to discriminate between black cards and white cards, half of them to enter the arm of the maze with the black card and half to enter the arm with the white. The only function of these leader rats, however, was to provide discriminative stimuli for the rats that were to follow them.

When the leader rats had learned to turn in the direction indicated by the appropriate card, they were used to train the "follower" rats to imitate a specific item of behavior. First, a leader was placed in the start box at the be-

ginning of the stem, with the follower in a second box immediately behind it. When the leader was released from its start box, it promptly ran to the choice point at the intersection of the T and turned in the designated direction. At the end of the arm, it received its usual allotment of food. The follower rat was released immediately behind it. If the follower rat turned in the same direction as its leader, its response was reinforced with food in a special receptacle uncovered only after the leader rat had passed over it. If the follower rat turned in the other direction, however, its response was not reinforced.

For the follower rat, then, the leader turning to the right was a discriminative stimulus for turning to the right, and the leader turning to the left was a discriminative stimulus for turning to the left. As might be expected, the follower rats had no difficulty in mastering this discrimination. With respect to this one response, their behavior matched or imitated the behavior of their leaders. However, in terms of learning principles, there was nothing unique about the resulting correspondence between the behavior of the 2 animals. To demonstrate this point, Miller and Dollard (1940) trained another group of follower rats in a pattern of stimulus control that was exactly the opposite of imitation: Turn left when the leader turns right and turn right when the leader turns left. The two groups learned their tasks with equal facility. Following a partner in ballroom dancing may provide an illustration of this reversed relationship, but such a pattern of stimulus control is not commonly reinforced in the outside world.

Apparently there is more to imitation, however, than establishing discriminative control over a single response. When a number of correspondences have been reinforced between the actions of an experimental subject and the actions of a model, the correspondence itself may become a governing factor in the relation between the two actions, extending to new to-

pographies of behavior. Baer, Peterson, and Sherman (1967) demonstrated this with 3 profoundly retarded children who originally showed no tendency to imitate. In the beginning, the experimenters used manual guidance and selective reinforcement with food to establish a series of physical actions like raising the left arm, tapping a table, or moving the arm in a circular motion, each of which followed a like action by the experimenter.

One of the things these authors showed was that the behavioral correspondence could itself be placed under the control of some other stimulus in what was therefore known as a conditional discrimination. In their study, reinforcement of the child's action was conditional upon the prior presentation of the verbal stimulus, "Do this," followed by a demonstration of the desired response. Stimuli in the presence of which correspondence is reinforced determine when imitation will occur and when it will not occur. In some studies, the choice of a model has determined when correspondence would be reinforced.

In the Baer et al. (1967) study, 130 different responses were employed. Eventually the children began to imitate new actions, demonstrated for the first time. Some of these were repeated on a number of test trials, still without reinforcement, interspersed among training trials on which other actions were reinforced. The performance of these nonreinforced actions continued to depend, however, on the general tendency to perform responses demonstrated by the experimenter. When reinforcement of the main body of responses was replaced by differential reinforcement of other behavior, the never-reinforced test actions also dropped out. Both sets of behavior were restored with restoration of the original reinforcement schedule.

Similarity to the behavior of the model may also serve as a conditioned reinforcer. In another experiment, Lovaas, Berberich, Perloff, and Schaeffer (1966) reinforced the production of

English words by each of 2 autistic children, in response to those same words presented by an experimenter. Then some Norwegian words were slipped into the sequence, without reinforcement; with continued reinforcement of the English words, the pronunciation of the Norwegian words gradually improved. These data suggest that the increasing similarity between the sounds produced by the child and the sounds presented by the experimenter had itself become reinforcing, leading to successive approximations of those sounds by the children.

STIMULUS EQUIVALENCE

In his presidential address to the Midwestern Psychological Association, Skinner (1950) included brief résumés of several pieces of work conducted in his laboratory that were never subsequently reported in greater detail. Among these was a procedure that he called "matching to sample," presented in an attempt to strip some of the surplus meaning from what would nowadays be called "cognitive" descriptions of choice and other complex patterns of behavior.

The pigeon was confronted with three keys, arranged in a horizontal row. First, on a given trial, the middle key was illuminated with a sample color, perhaps red or green. When the bird pecked that key, the sample color was extinguished and the keys on either side were lighted with the comparison colors. One of these colors was the same as the sample, and the other was different. In a strict matching-to-sample procedure, it was a peck on the same-color key that was reinforced. In what later came to be known as oddity matching, it was a peck on the different-color key that was reinforced. With a delay introduced between the darkening of the center key and the lighting of the side keys, Skinner's procedure was widely used by more cognitively oriented psychologists to analyze the processes involved in responding to past events (memory).

Years later, Sidman (1971, 1994) adapted Skinner's procedure to the task of teaching a severely retarded boy to read English text. Prior to the procedure in question, this boy had already learned correspondences in both directions between spoken words and pictures. That is, he had learned to choose the pictures that illustrated the words presented as sample stimuli and to produce the correct vocal responses to (name) the pictures. During the training procedure, the sample stimuli were words spoken by the experimenter, and the comparison stimuli were printed words. Somewhat to Sidman's surprise, after his subject learned to choose the printed word that corresponded to each spoken word, not only was he able to proceed in the opposite direction, producing the correct oral responses to printed text (reading aloud) but, without further training, was able to choose pictures corresponding to the printed words (reading comprehension). Establishing an equivalence between the auditory and the visual forms of a series of words had extended the subject's ability to select the correct pictures from the original spoken words to their printed equivalents.

Struck by these initial findings, Sidman launched a major program of research designed to explore their theoretical ramifications (Sidman, 1994). Because there is now a burgeoning literature on the topic, it may be important to consider some terminological issues. First, Sidman objected to the use of the term *matching to sample* as a description of Skinner's procedure, on the grounds that this phrase implied a generalized behavioral outcome that did not necessarily result from that procedure. In its place, he substituted the phrase *conditional discrimination*, first applied by Cumming and Berryman (1965). Generically, the term *conditional discrimination* covers more than the matching-to-sample paradigm (see Yarczower, 1971), but in the Cumming and Berryman usage an additional, extraneous stimulus (e.g., a red sample or a green sample) determines which of

the alternative stimuli (in this case, red or green comparison stimuli) in a discrimination is positive (i.e., followed by reinforcement of the response). The relation between comparison stimulus and reinforcer is selected by or conditional upon the nature of the sample stimulus. When the sample stimulus is red, pecking red is reinforced and pecking green is not reinforced; when the sample is green, pecking red is not reinforced and pecking green is reinforced.

Sidman (1994) has also suggested the use of the term *conditional stimulus* to refer to the role of the sample stimulus in this type of discrimination, but such a usage could lead to terminological confusion, because that term is widely used in Pavlovian conditioning to refer to the stimulus that acquires its effectiveness through its temporal relation to the unconditional stimulus. The terms *instructional stimulus* (Cumming & Berryman, 1965) or *contextual stimulus* (Sidman, 1994) have also been suggested; the former term has intuitive appeal, and the latter term has the advantage of emphasizing that stimuli and responses usually do not pair off in a simplistic one-to-one correspondence, as sometimes implied in early writings by Watson (1919), for example, but are characteristically related in a way that depends on what other stimuli are present (context).

Although an exposition of the nature of the procedure we are considering has been greatly simplified by the use of physically identical colors as exemplars, in establishing equivalence classes the experimenter utilizes stimuli that bear no necessary resemblance to each other and establishes their correspondence through the program of training. A quantity of objects, for example, and the corresponding numeral begin as arbitrary, unrelated stimuli, but the standard relations characteristic of a given language can be established through this type of training. Eight objects can be made equivalent to the digit "8" and the binary number "1000" and the sound "ate" and the

printed word "eight" and even the Spanish word "ocho," thus forming a class, all of whose members may be said for our purposes to be equivalent. When they become members of the same class, they are for many purposes interchangeable. If we respond in the same way to these physically very different stimuli, they may be said to have the same meaning.

Sidman (1994) has laid out three criteria, all of which are necessary to the mathematical definition of an equivalence relation among a set of stimuli. *Reflexivity* requires that, without specific instruction or training, the subject choose each stimulus in the list as a comparison in reaction to that same stimulus as a sample (i.e., generalized identity matching). *Symmetry* requires that the subject perform correctly when the roles of sample and comparison stimuli are reversed. *Transitivity* involves three stimuli in a sequence. Once "if a, then b" and "if b, then c" have been established, then "if a, then c" must emerge without further instruction or training.

The apparent significance of equivalence classes for what are sometimes known as higher mental processes is currently attracting a considerable amount of attention within the behavior-analytic community. Quite a bit of research has recently been reported, accompanied by a large amount of theorizing. However, it remains a relatively new field of investigation, still in flux, and the available information does not as yet permit us to be sure how it fits into a broader, more systematic framework.

One active program of research stems from Fields and Verhave's (1987) analysis of the parameters that define the internal structure of an equivalence class. In a review of the relevant literature, Fields, Adams, and Verhave (1993) examined the effects of two of these parameters. *Directionality* refers to whether a stimulus serves as a sample or a comparison in the process of training. In several studies, this relation was found to influence the

likelihood of class formation, the formal characteristics of specific emergent relations, and the degree of transfer between stimuli. *Nodes* are formally defined as individual stimuli that are linked by the program of training to more than one other stimulus within the particular equivalence class; they may be thought of as intervening steps or mediators of the relation between stimuli that were not presented together during the training. And *nodal distance* refers to the number of such steps that lie between the stimuli that are to be tested. In a number of studies, the authors found, this parameter had a consistent influence on the subjects' performances on a number of different types of test. A point of emphasis in their review was that functions acquired by one stimulus in an equivalence class do not transfer equally, but rather differentially, to other members of the class. The relatedness of the stimuli is affected by the directionality of training and is an inverse function of nodal distance.

The relation between the formation of equivalence classes and earlier, simpler forms of discrimination learning remains the subject of wide-ranging discussion. Still in dispute, for example, is the question of whether emergent relations and stimulus classes can be demonstrated with nonhuman subjects (see Schusterman & Kastak, 1993; Zentall & Urcuioli, 1993). Sidman (1994) has suggested that the formation of equivalence classes through conditional discrimination training may not be reducible to or explicable by other processes with which we are already familiar but may be a wholly independent phenomenon grounded in the evolution of the human species. For those of us in search of systematic laws of behavior, this is not a very satisfying solution. Hayes (1991), on the other hand, has suggested that equivalence classes can be traced to a preexperimental history of training in relational responding. At the present time, such issues are far from being resolved.

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